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14. ABSTRACT

This research investigated people's ability to recognize configurations in space from different points of view under both uni- and multi-tasking conditions. Past research suggested that people might perform this kind of problem solving using either mental rotation or covert verbal descriptions. We hypothesized that use of these two strategies might depend on the verbal discriminability of the spatial scene. We also hypothesized that the strategy chosen might depend on the performance of a concurrent task. Specifically, in attempting to reduce processing interference, we predicted that people would be more likely to use mental rotation when the concurrent task they were involved in was verbal rather than spatial; conversely, they would be more likely to use verbal descriptions when the concurrent task was spatial rather than verbal. These hypotheses were supported in a series of experiments in which we measured people's time to decide whether spatial configurations displayed from different perspectives were the same or different, while they performed various types of concurrent tasks.

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OBJECTIVE: This research sought to 1) develop a set of experimental methodologies that could be used to investigate spatial reasoning strategies under timed, multiple-display conditions; 2) conduct a series of experiments examining the processing strategies people use to recognized spatial configurations in uni- and multi-tasking conditions; and 3) train students to generate research questions, develop experimental materials, collect and analyze data, and write up results for presentation and publication.

APPROACH: In our studies, participants viewed pairs of near-photorealistic 3D scenes from different points of view. One of their tasks was to say whether the configurations depicted in the scenes were the same or different. While performing this task, participants were also asked to perform a secondary task, for example, keep in mind a sequence of consonants or abstract symbols. Tasks that draw on the same set of mental resources can lead to selective interference. This paradigm allowed us to study not only the strategies people use in the localization of objects, but also their ability to flexibly change strategies as a function of concurrent task demands.

ACCOMPLISHMENTS: Since the beginning of the project in July 2001, we ran over 800 participants in 15 experiments. The work included constructing over 2,600 3D images and 10 relatively complicated presentation programs.

During the course of project, my students and I examined the kinds of mental processes people use to recognize spatial configurations from various perspectives. Our research was based on the idea that people use at least two main strategies in determining whether two spatial configurations are the same or different. One of these strategies is *mental rotation* (e.g., Cooper, 1975; Cooper & Shepard, 1973; Shepard & Metzler, 1971; Tarr & Pinker, 1989, 1990). An observer might mentally rotate a configuration to test whether it aligns with another configuration viewed from another perspective. Another strategy people might use is to compare *verbal descriptions* of the two scenes (Bethell-Fox & Shepard, 1988; Hermer-Vazquez, Spelke, & Katsnelson, 1999; Simons, 1996). Upon viewing a scene, an observer might covertly code certain aspects of the scene in linguistic terms. For example, in a scene depicting a woman and a couch (see Figure 1 below), they might silently tell themselves "the woman is standing in front of the couch." Upon seeing the scene from another perspective, the observer might form another verbal description and then compare it to the former to determine whether the scenes are the same.

In one line of experiments, we examined some of the stimulus conditions that lead people to recognize spatial configurations using either mental rotation or verbal descriptions. In an important **initial** experiment (N=40), we investigated how processing
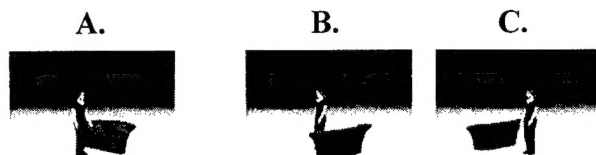
Figure 1. In Scenes B and C, a simulated camera is panned 90° from where it was in Scene A. In scenes A and B the configurations are the same while in Scenes A and C they are different.

might be influenced by the *verbal discriminibility* of a configuration. Participants (N=40) saw two scenes arranged side-by-side on the screen. Each scene contained a pair of objects that included a figure object (e.g., a woman) standing in front of or behind a ground object (e.g., a couch) (see Figure 1). In half of the scene pairs, the entities were configured in the same way while in the remaining pairs they were configured differently. In roughly 90% of the scene pairs, the two scenes were rendered (computer drawn) from different perspectives (e.g., 0° & 45°, 0° & 270°) while in the remaining pairs (~10%) they were rendered from the same perspective. The images were based on 24 different ground objects. Half of the participants saw configurations containing objects (N=12) with inherent front and back sides (see Figure 2, panel A), while the remainder of the participants saw configurations containing objects (N=12) without inherent front and back sides (e.g., see Figure 2, panel B). We measured people's time to say whether the
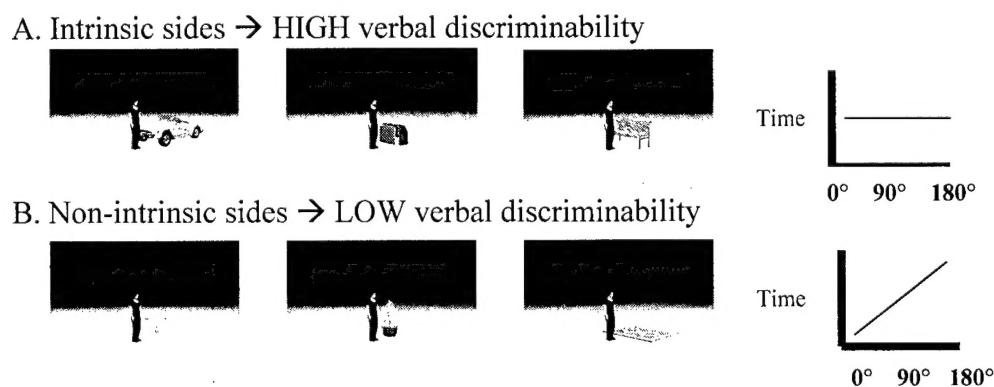

Figure 2. Panel A shows configurations containing entities with inherent front and back sides while Panel B shows configurations containing entities without inherent front and back sides, along with the predict pattern of reaction times for the two types of configurations. A flat slope across different disparities in perspective, as shown in Panel A, suggests use of verbal descriptions, while a linearly increasing slope, as shown in Panel B, suggests use of mental rotation.

configurations were the same or different. As predicted, reaction times for the high-verbally discriminable scenes were equally fast from each camera angle—suggesting use of verbal descriptions—while RTs for the low-verbally discriminable scenes increased linearly with increases in the disparity in camera angle—suggesting the use of mental rotation (see Figure 3). One small but important departure from the predicted results occurred in the case of the high-verbally discriminable scenes. Participants responded faster to zero differences in angular disparity, 0°, than to the other differences (see Figure 3). We interpret this break from the main pattern as signaling a shift in processing: when the scenes are precisely the same, people probably rely on a superficial, template-based, matching procedure—rather than verbal descriptions—to determine whether the scenes

are the same or not. Hence, people may use verbal processing only when integrating their knowledge about spatial relations across different points of view. While the results from this experiment were consistent with our hypotheses, they were also consistent with the possibility that people used distinctive asymmetries in the reference objects of the high-verbally discriminable scenes to match the scenes.

A **second** key experiment addressed this limitation. Participants (N=80) were shown the same high-verbally discriminable scenes as before and asked to say whether they were the same or different. In this experiment, however, half of the participants saw pairs of scenes that differed in more than one way: not only did the woman sometimes appear on the opposite side (as before), she was also sometimes turned 180-degrees. Because the scenes could differ in more than one way, using verbal descriptions would have required participants to encode more than one proposition (e.g., The woman is in front of the couch with her left

Figure 3. Mean reaction times and associated standard errors as a function of the differences in angular disparity between the two scenes.

hand closer to the couch than her right hand), and hence form more complex verbal descriptions. As predicted, the reaction times (RTs) for participants seeing pairs of configurations that differed in more than one way increased linearly with camera angle, suggesting use of mental rotation instead of use of verbal descriptions. However, the RTs for participants seeing configurations that differed in only one way were flat, suggesting use of verbal descriptions. Thus, people tended to use verbal descriptions when those descriptions were relatively easy to generate; otherwise, people used the more time-consuming process of mental rotation.

In a **third** key experiment (N=40), we provided further evidence for the use of verbal descriptions by varying the scenes in terms of the "goodness" of the spatial relation between an object and a person. In half the scenes the person stood either directly in front of or behind the object. In the remaining scenes, the person stood slightly to the side of these relations. As predicted, participants' use of verbal descriptions was faster for good examples of these relations than for not-so-good examples.

In a **fourth** key experiment (N=80), we found that peoples' recognition strategies changed under multi-tasking conditions. Participants saw the same high verbally discriminable configurations used in the experiment described above. Half of the participants performed a concurrent task—repeating a list of numbers heard through earphones—while the rest simply viewed the scenes as before. Verbal repeating (shadowing) has been shown to selectively impair working memory for linguistic information. As predicted, participants performing this secondary task tended to match the spatial configurations using mental rotation—as indicated by linearly increasing RTs—while those not performing the secondary task appeared to use verbal descriptions—as indicated by RTs that remained constant across different camera angles. It is significant, however, in a shadowing task, that the primary and secondary tasks are performed together.
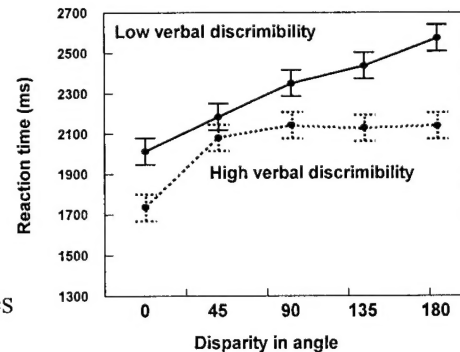
In a **fifth** key experiment (N=64) we examined what might happen when the primary and secondary tasks were performed sequentially. Participants saw the low-verbally discriminable scenes, as described above, in which both the position and the direction of the person were varied. In one condition, participants saw the scenes without a secondary task. Under these conditions, we found that people matched scenes using mental rotation just as they had before. In another condition, participants saw the scenes while simultaneously keeping in mind a small set of consonants. We predicted that in this task that people would continue to use mental rotation. To the contrary, participants often appeared to switch to verbal descriptions or to use both verbal descriptions and mental rotation, as indicated by reaction times that were intermediate between those associated with mental rotation and verbal descriptions. This finding raises the possibility that the verbal processes used in the verbal secondary task primed people to use verbal processes in the scene-matching task.

This conclusion was supported in a **sixth** key experiment (N=64) in which participants saw the same scenes but performed a visual/spatial-processing task (e.g., keeping mind a matrix of squares). We predicted that such a task would interfere with their default strategy of using mental rotation. Just the opposite occurred. The processes needed for the visual/spatial secondary task appeared to prime the use of yet another visual/spatial process, mental rotation. These results, along with others, suggest that performance of two tasks can lead to process priming, and not just process interference.

In a **seventh** key experiment (N=128), participants saw the high-verbally discriminable configurations, as described above. In one condition, participants saw the scenes without a secondary task. Under these conditions, we found that people matched the scenes using verbal descriptions, just as found in previous experiments. In another condition, participants saw the scenes while keeping in mind a small set of consonants (a verbal task) while in another condition they saw the scenes while keeping in mind a matrix of squares (a spatial task). Based on the results from Experiments 5 and 6, we predicted that the verbal secondary task would promote (process prime) use of verbal descriptions in the primary task of configuration recognition while the spatial secondary task would promote use of mental rotation. The results were as predicted.

CONCLUSIONS: Our findings suggest that the processing strategies people use to recognize spatial configurations depend on their ability to encode space in terms of language and the performance of a secondary task. Specifically, when verbal working memory is not filled and the spatial configurations are relatively easy to discriminate in terms of verbal descriptions, people appear to recognize configurations using verbal descriptions, but when verbal working memory is filled—due to a concurrent task—or when the spatial configurations are not easily discriminated in terms of verbal descriptions, people match spatial configurations in terms of mental rotation.

SIGNIFICANCE: There has been relatively little research on how people recognize spatial configurations from multiple points of view while simultaneously performing other tasks. This research addresses, then, the spatial problem-solving strategies people use when tracking multiple objects (e.g., ships, aircraft) while also listening for verbal messages, monitoring warning lights, or repeating verbal commands. Findings from this research could inform future tests of spatial ability and cognitive flexibility, workstation design, or the linguistic codification of databases containing dynamic images (animation and video).

AWARD INFORMATION

Promotions

Director of the Program in Cognitive Psychology (8 faculty), University of Memphis, 2002-present

Invited Talks

Wolff, P. (Oct. 31, 2002). Categories of causation and configurations of force. Department of Brain & Cognitive Sciences, MIT.

Wolff, P. (Dec. 13, 2002). A force vector model of causal meaning. Department of Psychology, Vanderbilt University.

Wolff, P. (March, 2003; scheduled). Physical and psychological causation within a vector semantic framework. Lehigh University.

Wolff, P. (Feb. 11, 2002; scheduled). A force vector approach to causal meaning across languages. Max Planck Institute for Psycholinguistics, Nijmegen.

REFEREED PUBLICATIONS (for total award period):

1. Wolff, P. (in press). Direct causation in the linguistic coding and individuation of causal events. *Cognition.*

2. Wolff, P., & Zettergren, M. (2002). A vector model of causal meaning. In *Proceedings of the Twenty-fifth Annual Conference of the Cognitive Science Society.* Hillsdale, NJ: Erlbaum.

ABSTRACTS AND OTHER PUBLICATIONS (for total award period)

1. Wolff, P. (June 3-5, 2002). Object localization under uni- and multi-tasking conditions. Mississippi Consortium for Military Personnel Research, Memphis, TN.

2. Wolff, P., & Vassilieva, T., Burgos, F. (May 2 – 4, 2002). Language and mental rotation in the localization of objects. 2002 Annual Meeting of the Midwestern Psychological Association, Chicago, IL.

3. Wolff, P., & Wong, D. (Nov. 21-24, 2002). Causation and the concept of force. 43rd Annual Meeting Of The Psychonomic Society. Kansas City, KS.

4. Wolff, P., & Song, G. (October 11-14, 2002). Causal events: how perceptual properties are linked to linguistic expressions. The 6th Conference on Conceptual Structure, Discourse and Language. Rice University, Houston, TX.

5. Wolff, P., & Zettergren, M. (August 8-11, 2002). A vector model of causal meaning. The 25th Annual Conference of the Cognitive Science Society, Washington, DC.

IN PREPARATION (for total award period)

1. Wolff, P. (in preparation). Mental rotation and language in the recognition of spatial configurations.

2. Wolff, P. (in preparation). A force vector model of causal meaning.